

A grayscale topographic map of a mountainous region, likely a portion of a planetary surface. The map features numerous contour lines of varying thickness and spacing, indicating elevation changes. A prominent, dark, linear feature, possibly a ridge or a fault, runs diagonally across the upper half of the image. The overall texture is complex and detailed, typical of a high-resolution topographic map.

# **Photoclinometry Made Simple...?**

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# Photoclinometry made simple?

No, not really.  
Maybe simpler.

## Outline

- Photoclinometry: what, why, how?
- ISIS photoclinometry workflow
- Visualization examples
- Summary of new ISIS tools
- Interactive photoclinometry demo





# Photoclinometry...

- **What:** using brightness information in an image or images to infer topography
  - Also known as “shape-from-shading”
- **Why:** highly complementary to stereo
  - Works with a single image
  - Resolves single-pixel topographic details (vs. 3–5 pixels minimum for stereo)
  - Errors accumulate over horizontal distance
  - Sensitive to assumptions about surface photometry (wants constant reflectivity)



# Photoclinometry: How?

Many methods, classified by dimensionality of the region they give topography for

- Zero-dimensional: infer slope at a point from 1 pixel
- One-dimensional: integrate slopes along a line, build up elevation profile

1 known (brightness)  $\leftrightarrow$  2 unknowns (E-W, N-S slopes)??

Must assume slope direction: toward sun, along profile, or at known angle

- Two-dimensional: make a digital elevation model (DEM) of a region

*NB: this is actually a fully 3D model of a 2D surface*

1 known (brightness)  $\leftrightarrow$  1 unknown (elevation)

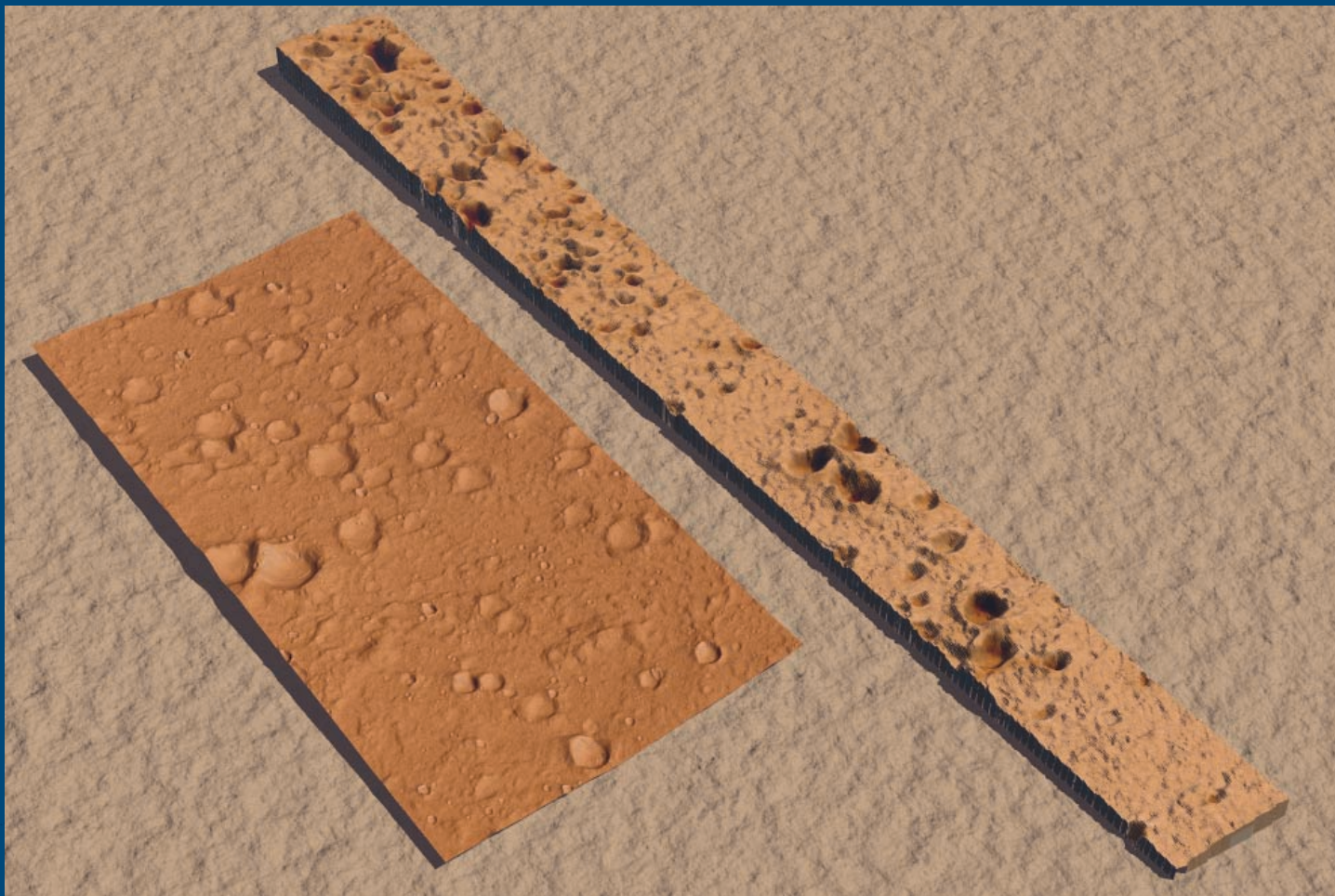
*A lot more data*

Totally different mathematical challenges

- A PDE with the image as forcing function
- Least-squares modeling an image
- The inverse problem to hill-shading



# Photoclinometry & Stereo



# 2-Dimensional Photoclinometry

## Kirk (1987) algorithm

- Set up finite element model of surface (just a DEM)
  - Elements=pixels; unknowns=pixel corner heights
- Set up eq<sup>n</sup>s for least-squares fit to image
- Solve by repeated linearizing (Newton-Raphson)
- Solve linear eq<sup>n</sup>s by successive overrelaxation (SOR)
  - Memory-efficient
  - Iterative
  - Converges local details first, long wavelengths slowly
- Multigridding (work at full, 1/2, 1/4,... resolution) to speed convergence of long wavelengths
- SOR+Multigridding require human supervision
- Supervision is not needed *if*
  - Image is very small (use direct matrix factorization not SOR) or
  - Have *a priori* DEM containing long wavelengths already





# Photoclinometry Workflow

- Select image
- Prepare image
- Prepare *a priori* DEM (optional)
- Estimate photometric parameters
- Estimate image normalization
- Do photoclinometry
- Post-process DEM
- Enjoy!



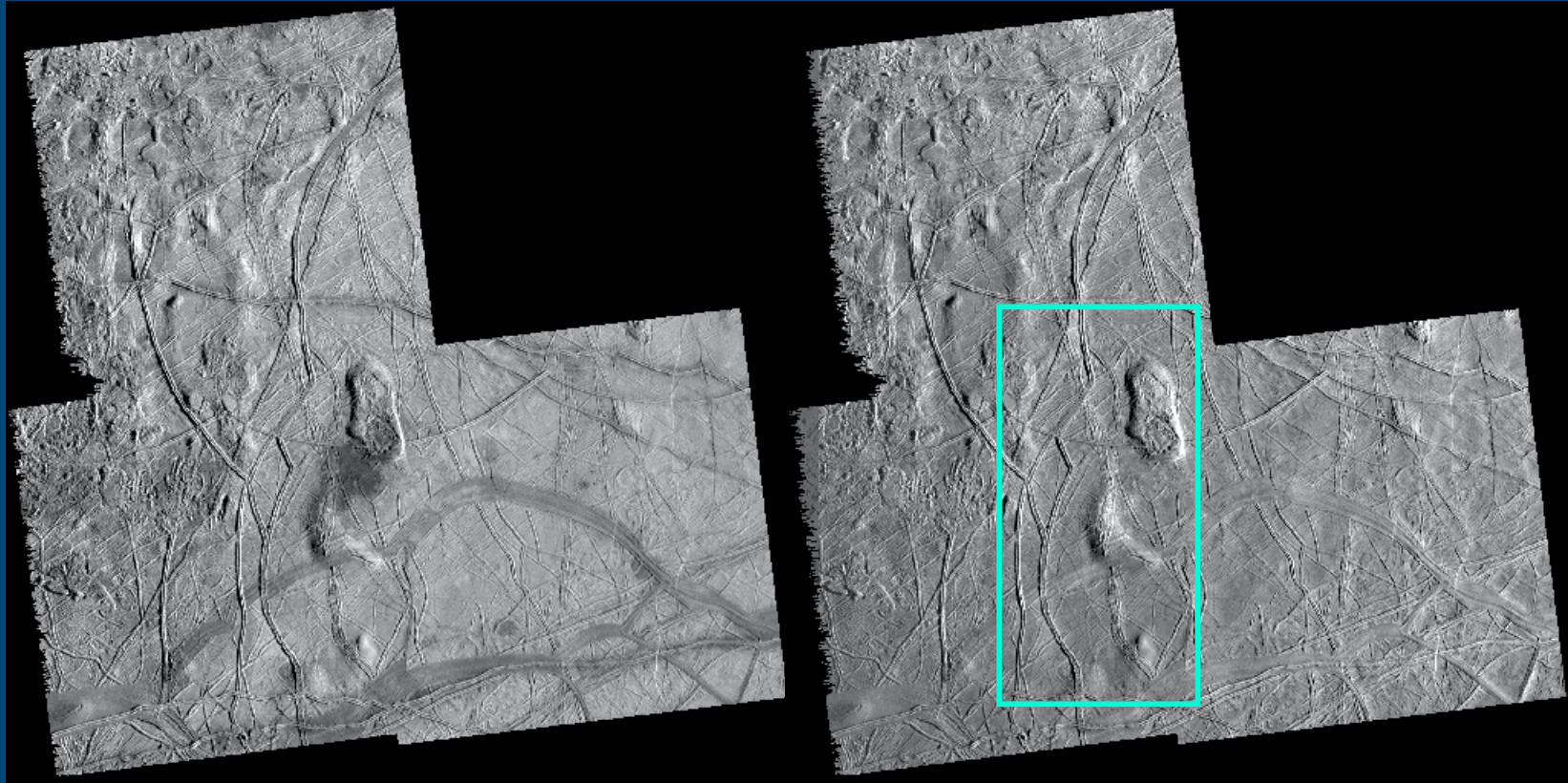
# Image Selection & Preparation

- Select image w/ shading >> albedo variation
  - Incidence angle > 30° but not too large
  - Minimal albedo variations visible to eye
- Perform radiometric calibration (Level 1)
  - Removes sensitivity artifacts
  - OK to convert back to lower bit type after
- Use framing or scanner images in native geometry (nonsquare scanner pixels are OK)
- Map-project if desired (Level 2)
  - Projection must be relatively undistorted
  - Single image, or
  - Mosaic of images with *similar illumination*—must transfer illumination info to labels with **lev1prop**

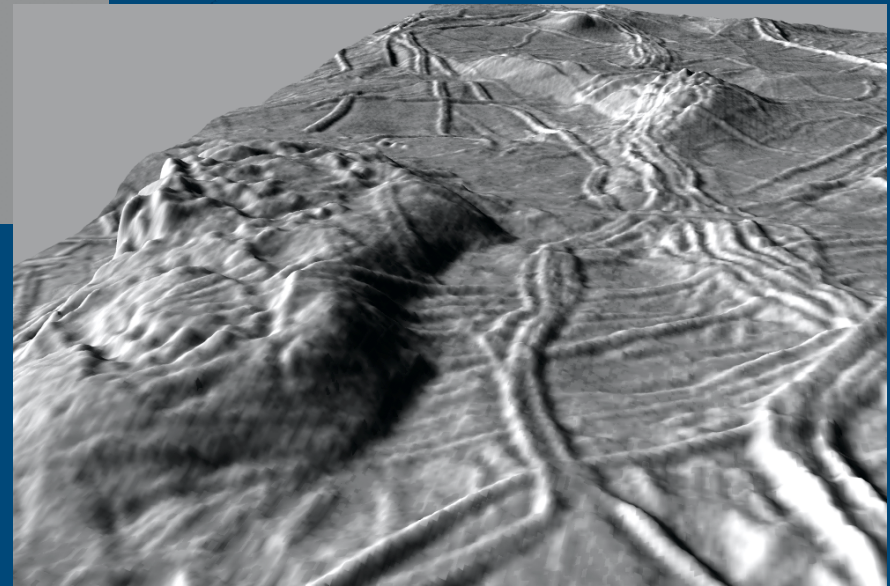
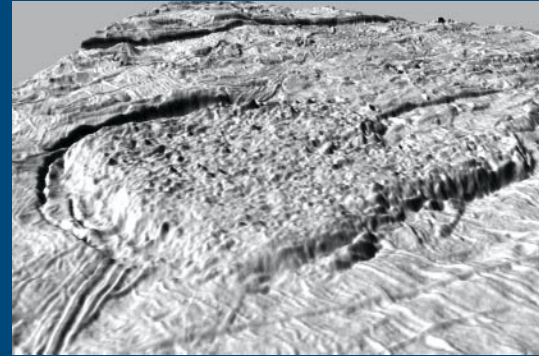
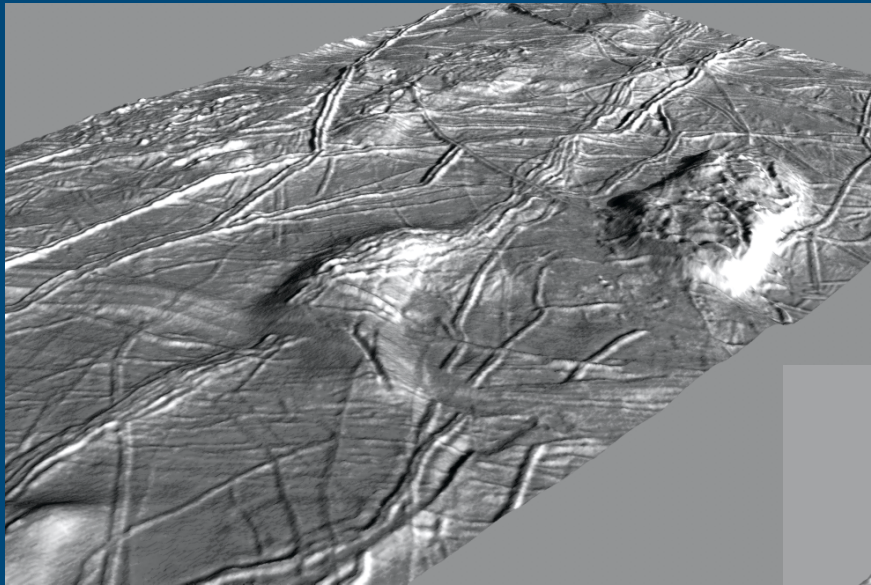




# Map Projection for Photoclinometry

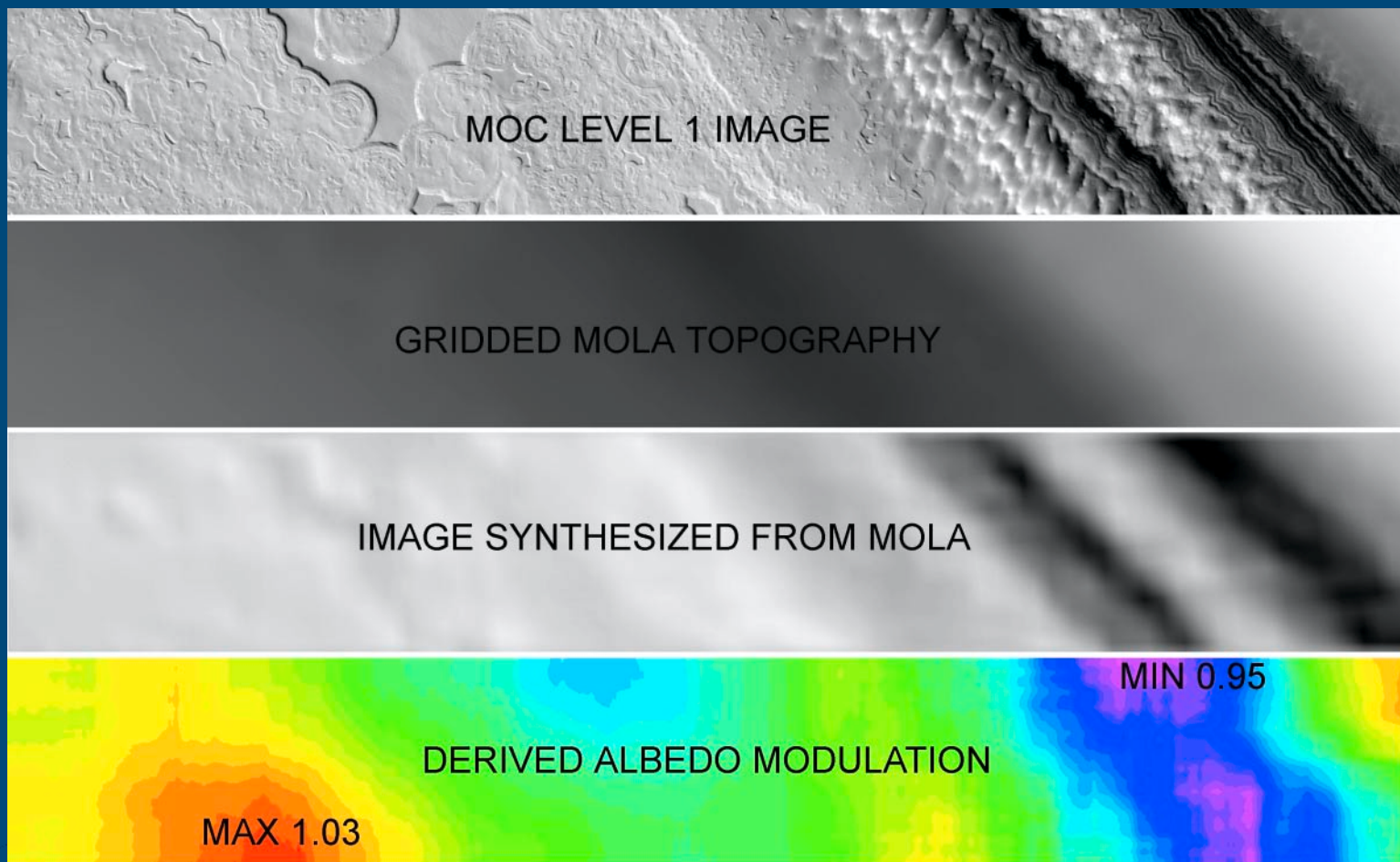


# Europa Visualized





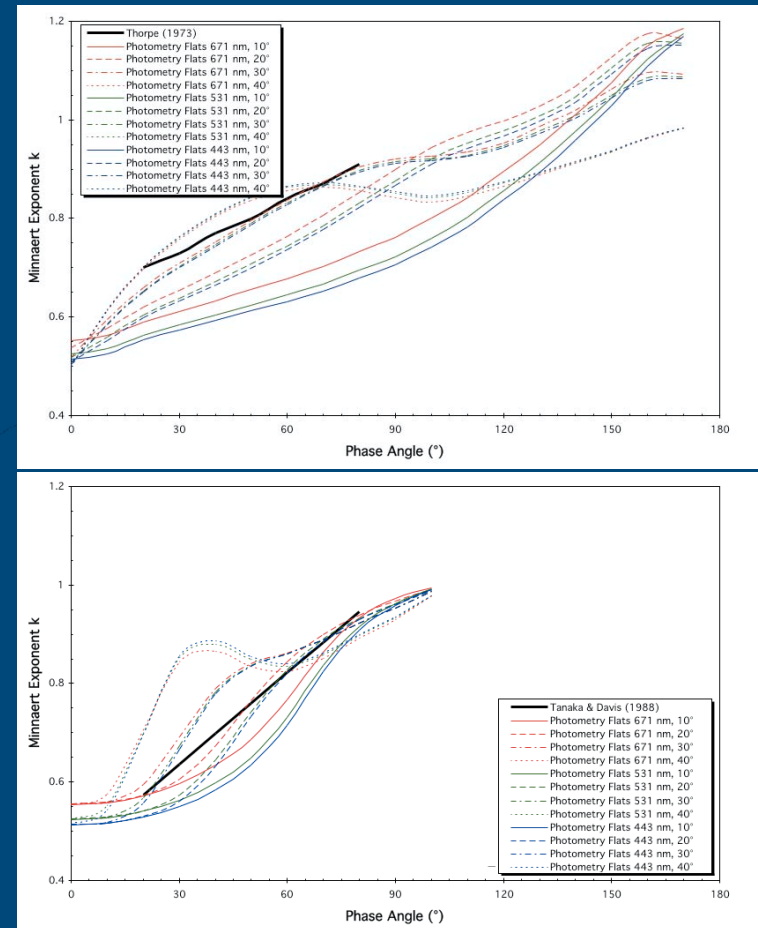
# Albedo Correction in Image Space





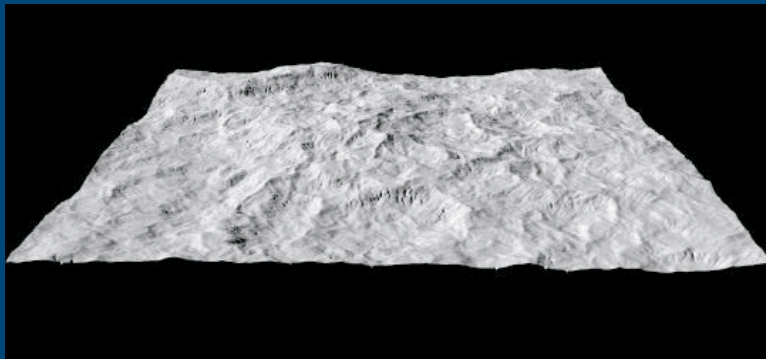
# Photometric Model Parameters

- Hapke model (5 physical parameters) supported but *slow*
- Minnaert, lunar-Lambert models (1 limb-darkening parameter)
  - Hundreds of times faster
  - Can be fit to Hapke model at given phase  $\alpha$  (McEwen 1991)
- **pho\_emp\_global** fits empirical to Hapke over whole hemisphere at series of  $\alpha$  mainly for mosaicking
- **pho\_emp\_local** fits at i.e.,  $\alpha$  of single image for photoclinometry
- Get Hapke constants from lit. (will summarize in PC documentation)
- Future programs will be useful for direct fitting of empirical models to images

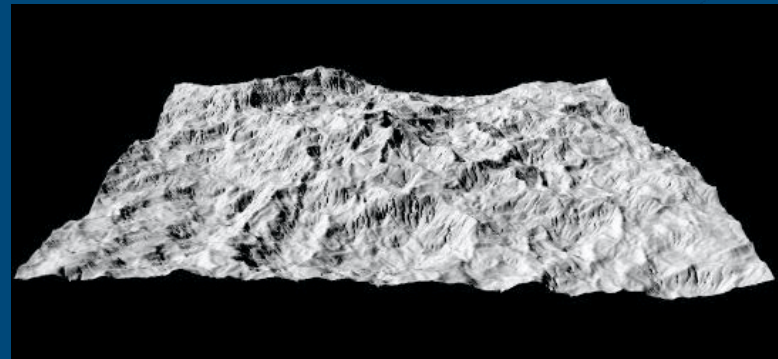


# Image Calibration Parameters: Haze and Albedo

Sun is from upper left in all examples



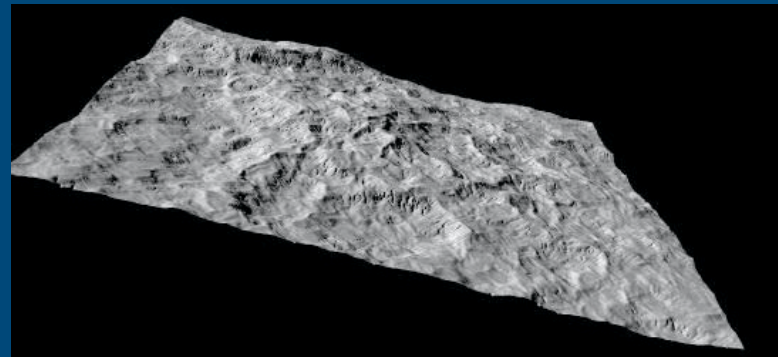
Correct Haze and Albedo



Too much Haze subtracted



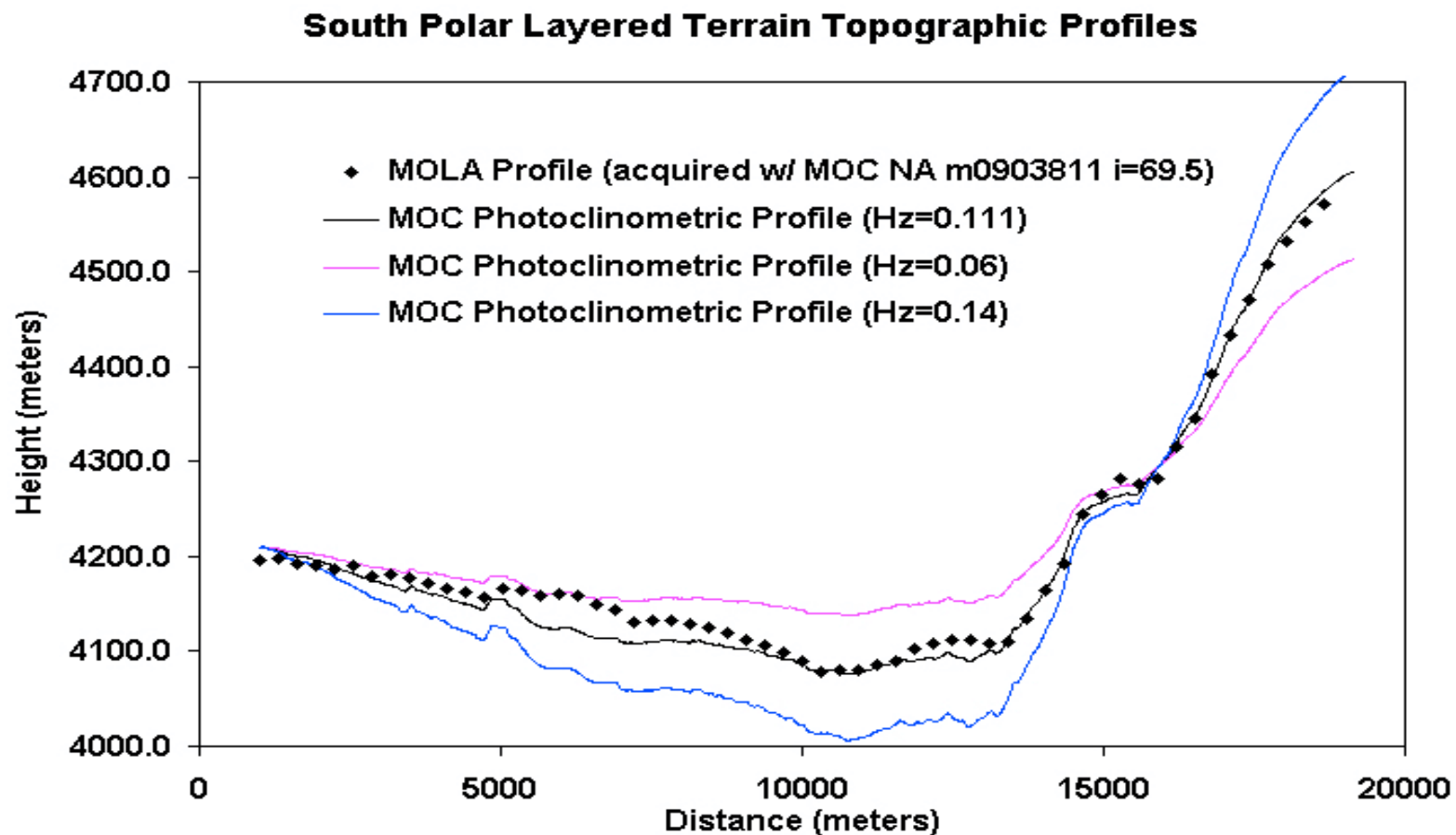
Albedo underestimated



Albedo overestimated

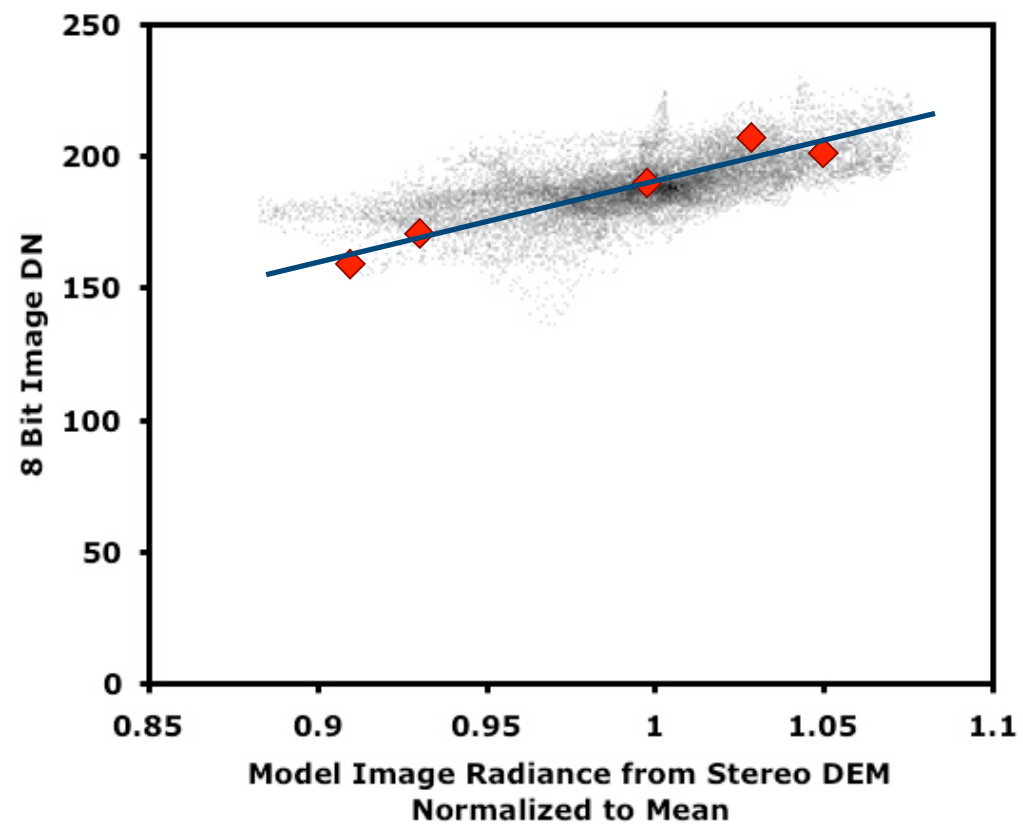
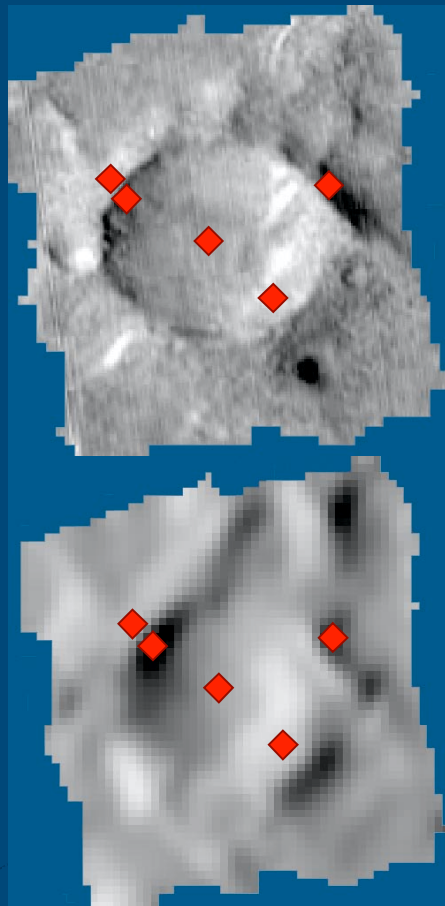


# Inverse Fitting for Haze: 1D Photoclinometry in Excel

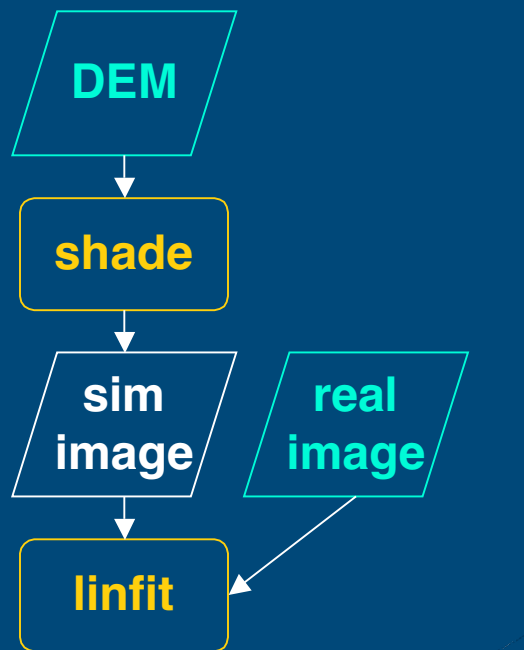




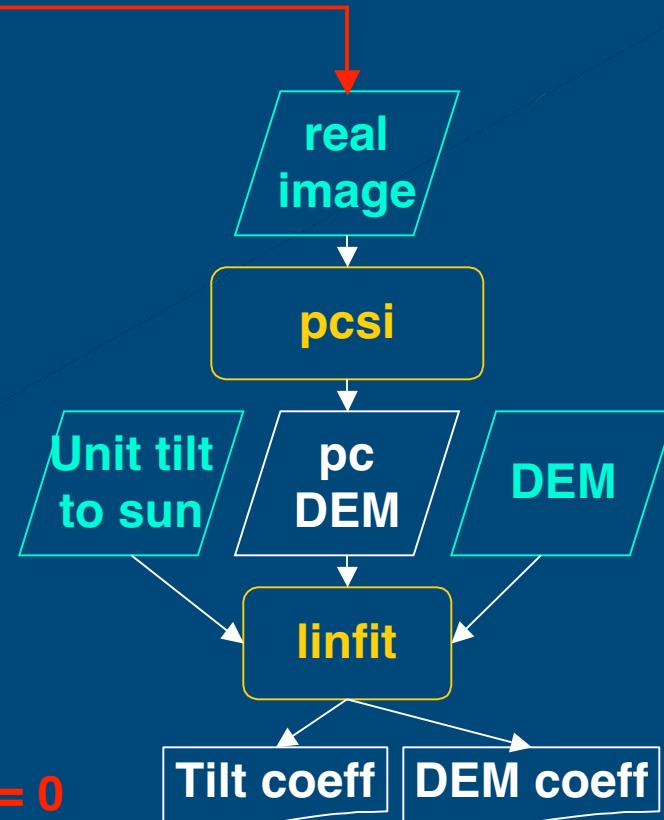
# Forward Fitting for Haze



# Automation of haze fitting: pc\_fit\_forward and pc\_fit\_inverse



Forward Method

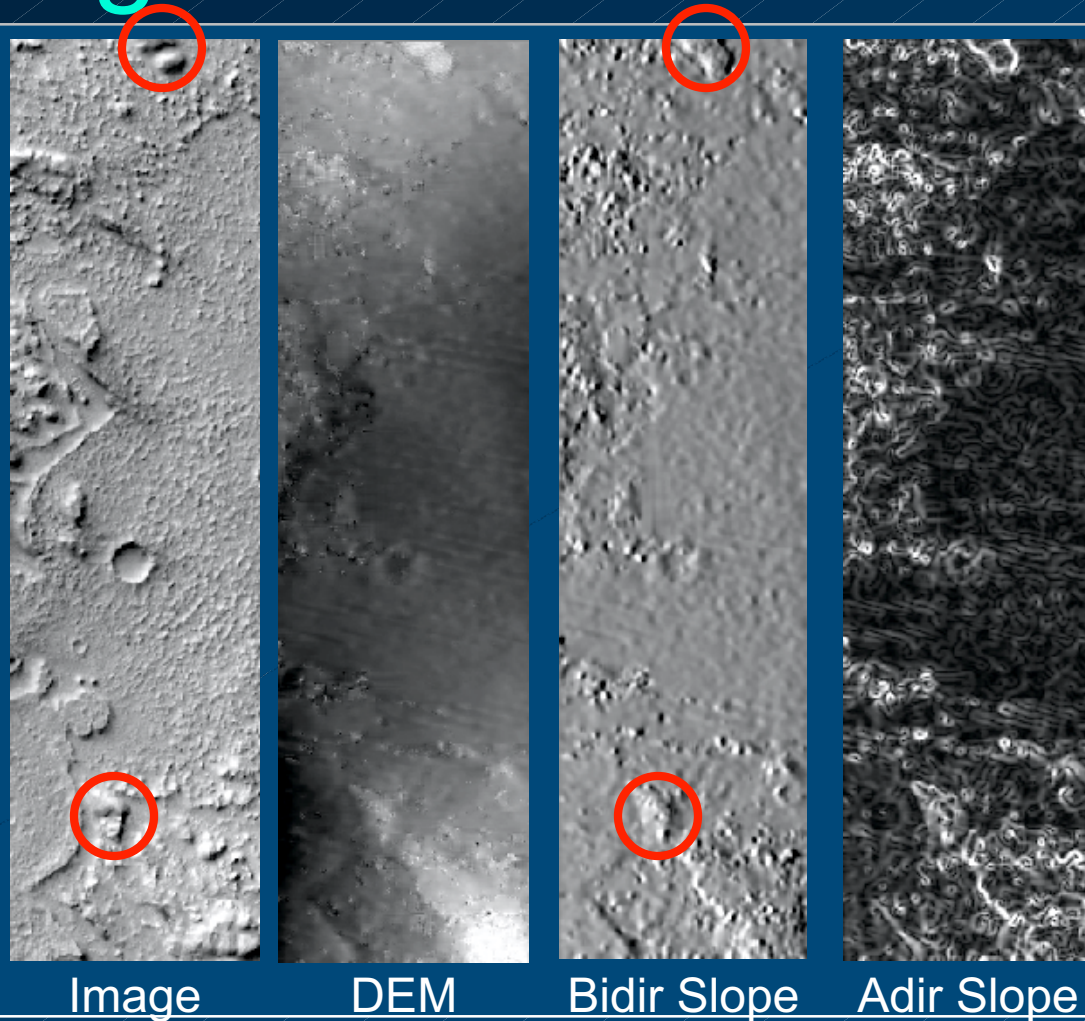


Adjust albedo  
until tilt coeff = 0  
Adjust haze until DEM coeff = 1

Inverse Method

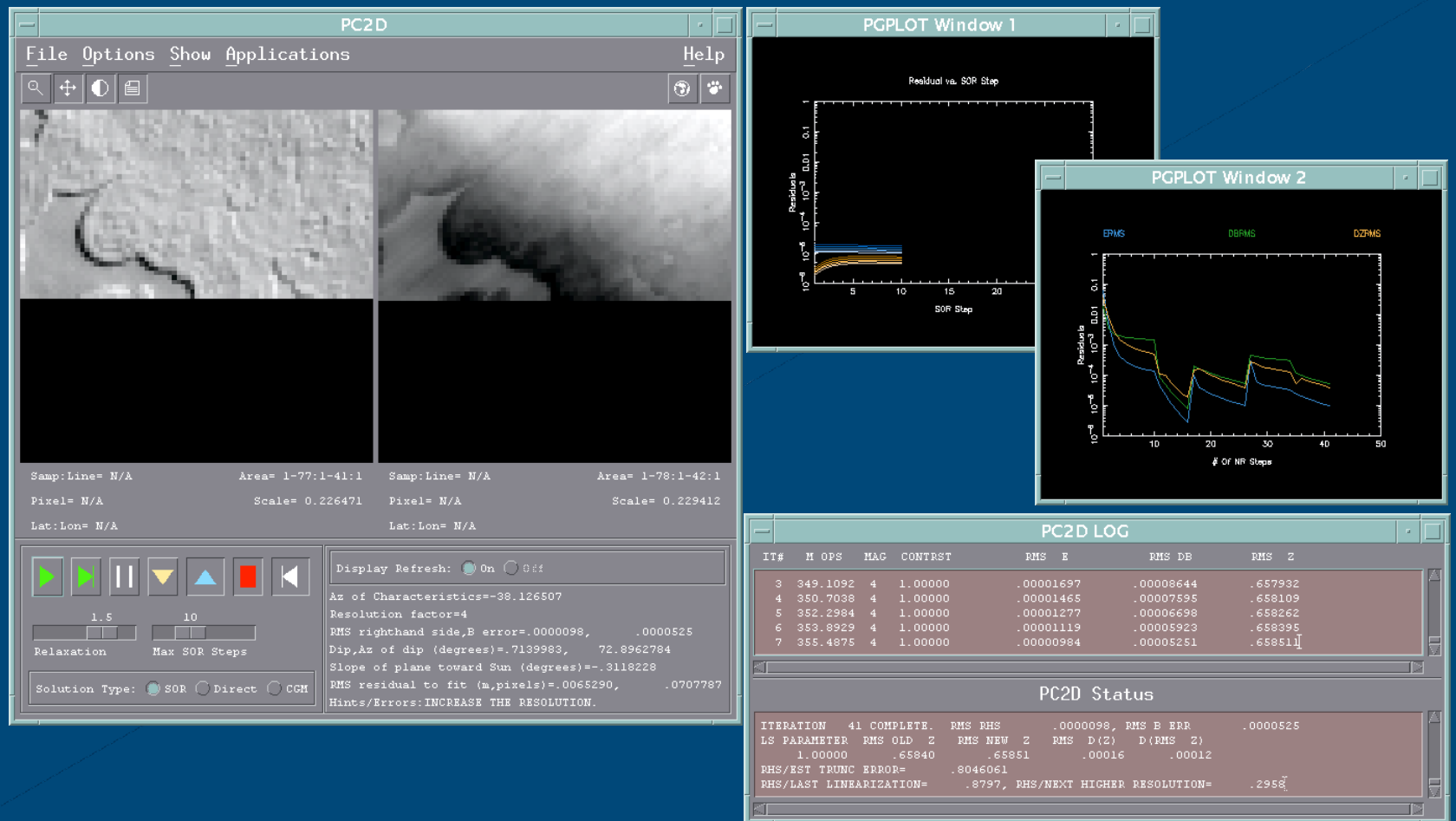


# Pitfalls of Haze Fitting: Finding well-resolved features

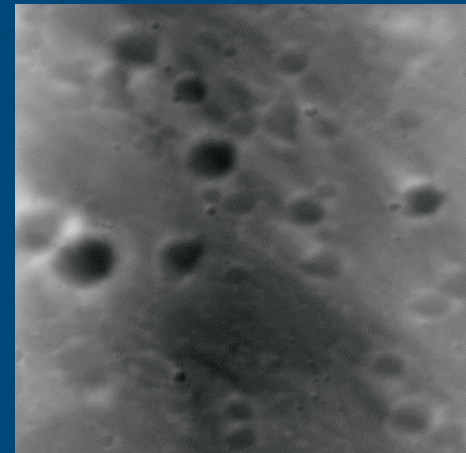
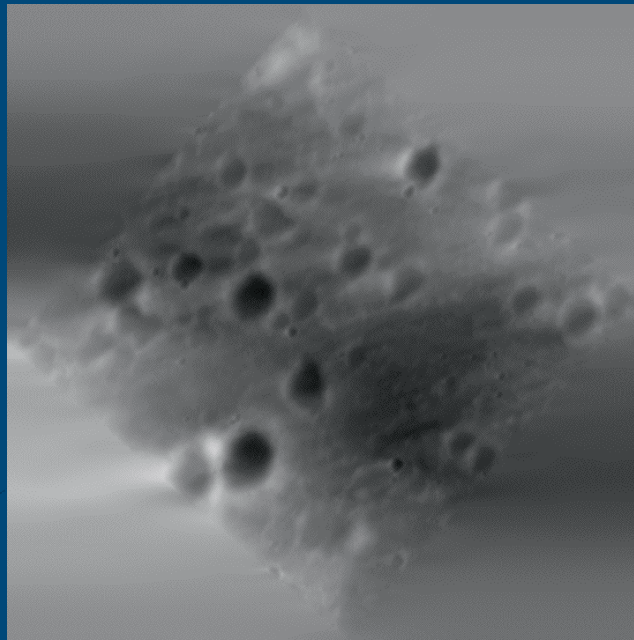
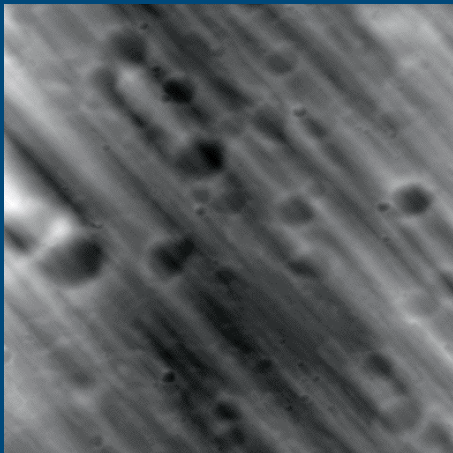




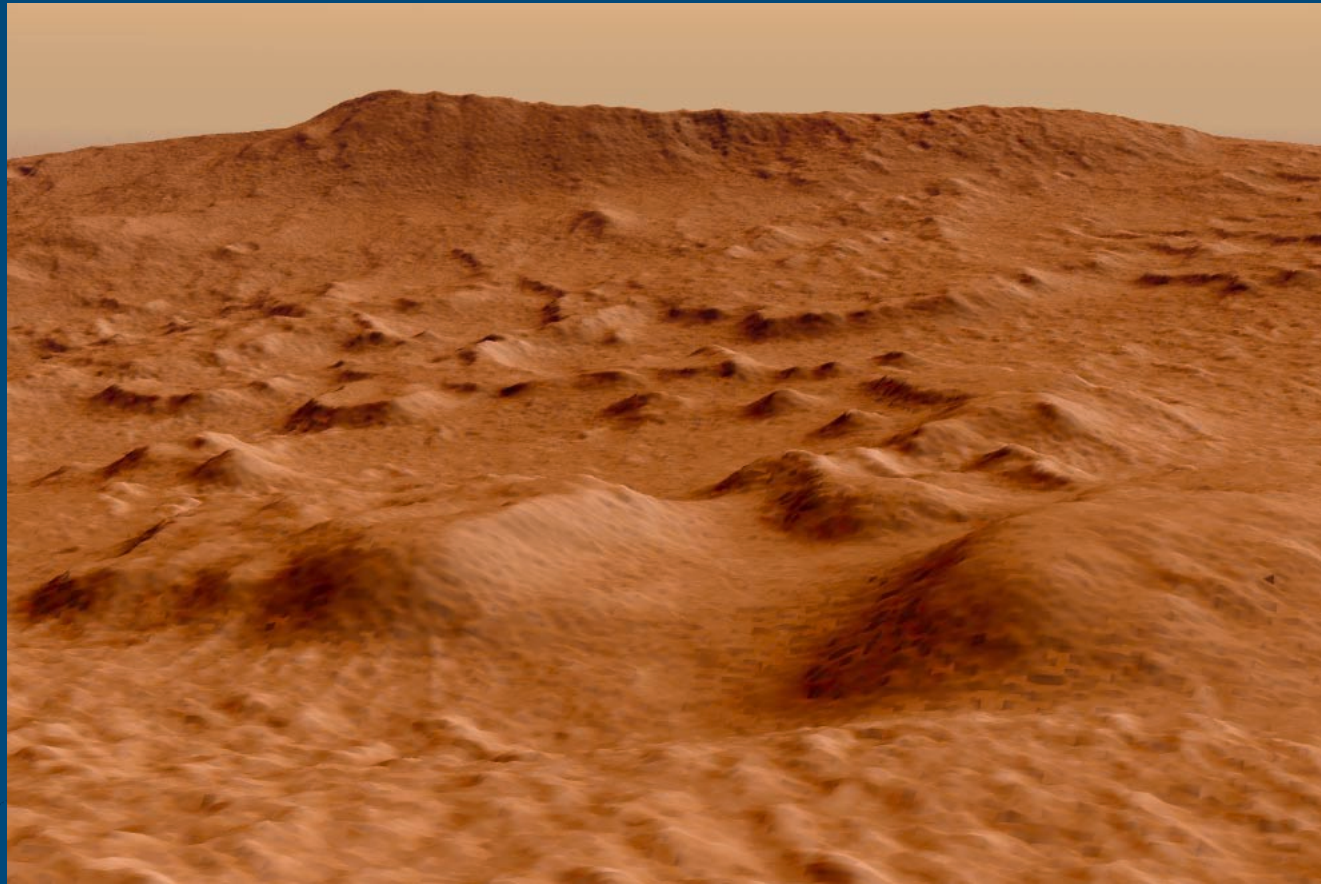
# pc2d Graphical User Interface



# DEM Post-Processing: “Destriping”

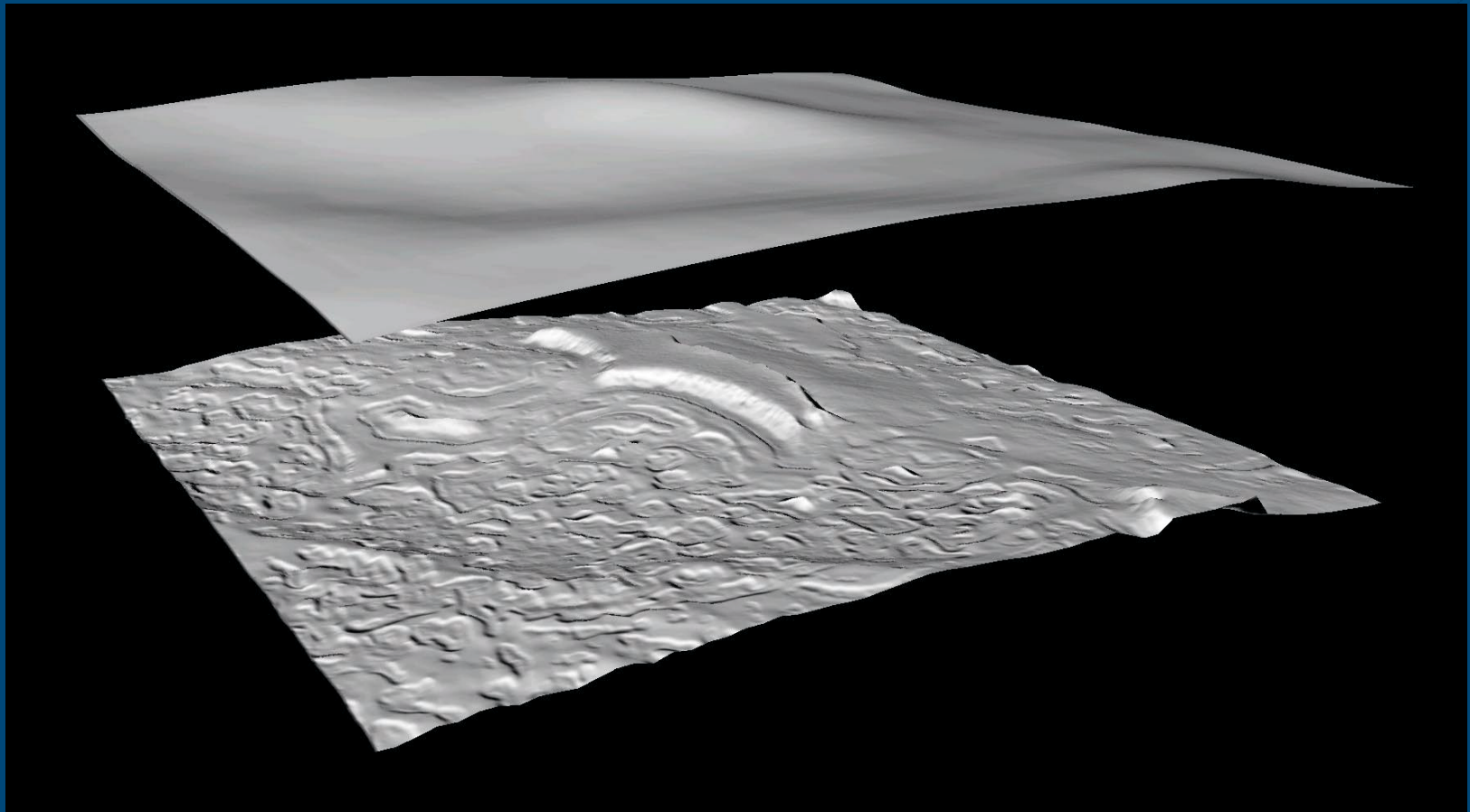


# Visualization Examples: Gusev





# Visualization Examples: PLT



# ISIS PC Tools Release 3/13/03

[astrogeology.usgs.gov/Teams/Geomatics/pc.html](http://astrogeology.usgs.gov/Teams/Geomatics/pc.html)

## Documentation

- Download & install information
- Improved TAE documentation
- Draft Photoclinometry User's Guide

## Photoclinometry

- **pc2d**—Interactive photoclinometry
- **pcsi**—Non-interactive photoclinometry
- **pcinfo**—Memory requirements & other info for **pc2d**, **pcsi**

## Photometric Normalization

- **photomet**—Improved documentation, consistent parameters

## Photometric Fitting

- **pho\_emp\_local**—Fit empirical fn to Hapke for mosaicking
- **pho\_emp\_global**—Fit empirical fn to Hapke for photoclinometry
- **shadow\_tau**—Improved documentation, consistent parameters
- **shade\_tau**—Atmospheric optical depth from global shading
- **pc\_fit\_inverse**—Haze fitting by trial photoclinometry (still pending)

## Support

- **lev1prop**—Geometric info to Level 2 labels for photoclinometry
- **linfit**—Linear regression of an image on 1 or 2 others

